

ON THE DEVELOPMENT OF THE SHELL OF *ZYGOS-  
PIRA RECURVIROSTRA*.

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The material showing the ontogeny of the shell in *Z. recurvirostra* was gathered from some blue-green shales on St. Anthony hill, a suburb of St. Paul, Minnesota. This horizon is equivalent to the lower Trenton of New York. Some of the associated brachiopods are *Orthis testudinaria*, *O. meeksi*, *Plectambonites sericea*, *Strophomena scofieldi*, *Clitambonites diversa*, etc.

The youngest specimen observed (plate xi, fig. 1) has a length of .8 mm., and is elongate subtriangular in outline, biconvex, with the ventral valve a little the deeper; ventral beak acuminate, inclined posteriorly at an angle of about 45° to the plane of the valves; delthyrium triangular, as wide as long and devoid of deltidial plates. In the apical portion there is a short concave plate continuous with the walls of the delthyrium, but apparently not attached to the rostral cavity. The fold and sinus are faintly developed, becoming obsolete at about the center of the shell and are without plications. In other individuals of about the same size the sinus is occupied by three short plications and the ventral fold by two. In specimens of a somewhat larger growth these primitive plications are rapidly followed by a number of new ones along the entire anterior margin. The size of the shell at which they begin to develop is variable (compare figs. 2-5), being the earliest in the narrow depressed individuals (fig. 3) and latest in the rounder and more convex specimens (fig. 4). New plications are rarely interpolated, their number being increased as growth proceeds by the addition of others along the lateral margins of both valves. The plications remain simple throughout.

The smooth nepiastic stage gradually grows more and more rotund and subquadrangular in outline, and at maturity is plicated to the apex of the shell. The ventral beak, which is at first slightly recumbent (fig. 1*a*), becomes erect, and finally is strongly incurved over the dorsal umbo (fig. 9*a*). The large

open delthyrium is gradually reduced in size by the introduction of deltidial plates which grow inwardly from the walls of the fissure, being wider anteriorly where they join, leaving in the apex an oval pedicle opening. As the beak incurves these plates become larger, stronger, and anchylosed along the median line, but at maturity are nearly completely hidden by the dorsal umbo. The pedicle opening at maturity (fig. 9) is through the acutely convex portion of the ventral umbo, and is comparatively smaller in size than during previous stages.

*Growth Stages.*—A well-preserved specimen of about 1.5 mm. length (fig. 10), shows three distinct stages of growth before the introduction of the plicated or specific period: *a*, the initial shell or protegulum, with both cardinal lines arched; *b*, a broad, oval stage, in which the ventral hinge areas on each side of the delthyrium first appear, followed by *c*, a subcircular form, with the beginning of the fold and sinus. It is either during stage *c* or *b* or both that the concave plate in the apex of the delthyrium is developed. During the next or fourth stage the first specific characters begin to appear, as shown by the plications, and also the first stage of the calcareous brachial supports.

#### *Observations and Correlations.*

The first or initial shell in *Zyggospira*, as in other brachiopods, is the protegulum, which has been compared with adult *Paterina* of the Lower Primordial. In many inarticulate brachiopods it is known that the protegulum is followed by a nearly round *Obolella*-like inarticulate stage, but in all rostrate articulate species in which the second stage has been observed there appears the first articulation of the valves. The fold and sinus, along with a few rudimentary plications, are introduced during the third stage of *Zyggospira*. This form of shell much resembles some primordial species which have been provisionally referred to *Camarella*. With but slight modifications in the convexity of the valves and the greater or less prominence of the fold and sinus, this form is repeated in a number of early Paleozoic genera of the suborders *Trullacea* and *Rostracea*, as primordial *Camarella* and many species of *Pentamerus*, *Zyggospira nicoletti*, *Camarella bisculata*, *Dayia*, and the so-called *Waldheimias* of the Upper Silurian. It is therefore impossible to refer with certainty on the basis of external character alone any Lower Silurian brachi-

opod of this form to any family of the Rostracea or to any rostrate family of the Trullacea. The presence or absence of deltidial plates at maturity, however, at once indicates the subordinal position of any rostrate species. If the rudimentary concave plate in the apex of the delthyrial cavity of nepiastic *Zygospira* has any phylogenetic significance, it shows that those families having deltidial plates and no spondylium, the Rostracea, had their origin in the Trullacea, a suborder in which the concave plate or spondylium is functional as a muscular fulcrum. This has already been inferred to be the case on other grounds, as geological occurrence and complexity of structure. A plate similar to that in nepiastic *Zygospira* exists in *Gerynia*, *Cistella*, *Atrertia*, and *Terebratulina*.

At the beginning of the fourth shell stage of *Z. recurvirostra* the species is recognizable as belonging to the suborder Rostracea and apparently most closely related to the Rhynchonellidae. The calcareous brachial supports first appear in a specimen about 1.33 mm. in length. The species is then referable to the Ancylobrachia, having a loop very much like that of *Centronella*. This loop then passes through a series of metamorphoses, acquiring spirals when the shell is about 3 mm. in length.

The mature exterior characters of the more prominent species of *Zygospira* will next be considered. *Z. nicoletti* (figs. 11, 11a, 12, 12a), one of the oldest species, retains many of the characters of the earliest period of the fourth growth-stage of *Z. recurvirostra*, and therefore more nearly resembles in form the primitive stock which gave rise to *Zygospira*. In *Z. saffordi* (figs. 13, 13a) the plications are more numerous than in *Z. nicoletti*, but reach the posterior third of the valves, and the shell is also more convex. *Z. recurvirostra* is larger, more convex, with a greater number of plications, which originate at the apex of the valves, and the ventral beak is more strongly incurved than in the species mentioned. From *Z. recurvirostra* one line leads through *Z. uphami* and *Z. erratica* to *Z. heudi*, comprising a group which continues to increase in size, gibbosity, striation, and in the obsolescence of the fold and sinus. In another phylum characterized by *Z. deflecta*, *Z. modesta*, *Z. cincinnatiensis*, and *Z. kentuckyensis*, the plications do increase in size but not in number, while the inconspicuous fold and sinus of *Z. recurvirostra* is gradually developed more and more strongly, so that when the extremes of both lines are compared (*Z. heudi* and *Z. kentuckyensis*) very

dissimilar exteriors are seen to have resulted from the same stock. *Zygospira* attained the greatest development in the Lorraine group of the Ohio valley. The species are usually very abundant in individuals, often forming groups several inches in diameter.

#### EXPLANATION OF PLATE XI.

- Figure 1.—Dorsal view of the smallest specimen observed of *Zygospira recurvirostra* Hall. The fold and sinus are just visible along the anterior margin of the shell.  $\times 12$ .
- 2.—A later stage, where the deltidial plates have begun to develop.  $\times 12$ .
- 3.—A specimen in which the plications are developed unusually early.  $\times 12$ .
- 4.—A specimen of larger growth than figure 3, in which the plications are slow in developing.  $\times 12$ .
- 5–8.—Different individuals to show the progression of growth in the deltidial plates and the extent of the plications over the umbones.  $\times 12$ .
- 9.—A mature example. The pedicle foramen is posterior to the deltidial plates, encroaching on the umbone of the ventral valve.  $\times 6$ .
- 1a–9a.—A series of profiles of the specimens, figures 1–9, respectively, showing the change in the convexity of the valves and the incurvature of the ventral beak.
- 10.—A specimen preserving the lines of growth very clearly, of which the stronger ones only are figured. The apex of the ventral beak has been worn away by abrasion and resorption by the pedicle. *a*, protogulum; *b*, the first articulate stage; *c*, the stage in which the fold and sinus are developed; *d*, the plicated stage; *e*, deltidial plates; *f*, pedicle opening.  $\times 25$ .
- 11, 11a.—An unusually large specimen of (*Hallina* =) *Zygospira nicoletti* W. and S., in which a few plications are developed on each side of the fold and sinus.  $\times 6$ .
- 12, 12a.—Dorsal and profile views of one of the types of (*Hallina* =) *Zygospira nicoletti* W. and S., the form most commonly observed.  $\times 6$ .
- 13, 13a.—Dorsal and profile views of the type of (*Hallina* =) *Zygospira saffordi* W. and S. This species is closely related to *Z. recurvirostra*.  $\times 6$ .